Climatic Change (2009) 94:319–331
DOI 10.1007/s10584-008-9501-2

Sustainable agriculture and the production of biomass for energy use

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Received: 24 April 2007 / Accepted: 21 August 2008 / Published online: 10 October 2008

Abstract Modern bioenergy is seen as a promising option to curb greenhouse gas emissions. There is, however, a potential competition for land and water between bioenergy and food crops. Another question is whether biomass for energy use can be produced in a sustainable manner given the current conventional agricultural production practices. Other than the land and water competition, this question is often neglected in scenarios to meet a significant part of global energy demand with bioenergy. In the following, I address this question. There are sustainable alternatives, for example organic agriculture, to avoid the negative environmental effects of conventional agriculture. Yet, meeting a significant part of global energy demand with biomass grown sustainably may not be possible, as burning significant quantities of organic matter—inherent in bioenergy use—is likely to be incompatible with the principles of such alternatives, which often rely on biomass input for nutrient balance. There may therefore be a trade-off between policies and practices to increase bioenergy and those to increase sustainability in agriculture via practices such as organic farming. This is not a general critique of bioenergy but it points to additional potential dangers of modern bioenergy as a strategy to meet significant parts of world energy demand.

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1 Introduction

Bioenergy[1] is becoming an ever more important option in climate change mitigation policies. The EU Directive 2003/30, for example, aims at increasing the share of biofuel use for automotive power in the EU to 5.75% by 2010 (EU 2003, from 0.8% in 2004 (EU 2005)). In the US, various initiatives to promote research in and to increase the shares of renewable energy and bioenergy in particular are planned or already launched, as stated in the President's State of the Union address 2007 (Whitehouse 2007) or the energy bill from 2005 (US Senate 2005).

This development has led to vivid discussions of potential problems regarding bioenergy production for scenarios where bioenergy is assumed to cover a significant part of global primary energy demand, say, a fifth (cf. e.g. Azar 2004). Most prominent is the potential competition for land between energy and food crops, based on assessments of land availability (Berndes et al. 2003; Azar 2004; Parikka 2004; Hoogwijk et al. 2003; Bhattacharya et al. 2003; Hoogwijk et al. 2005; Koopmans 2005; WWI 2006), and on the interaction of increased land demand with food production (Hoogwijk et al. 2003) and corresponding effects on land rents and food prices (Azar 2004). Some models also point out the importance of regional differences in land availability (see also FAO 2002b: 40). This information should be complemented with estimates of losses in arable land due to soil degradation and water scarcity in the context of conventional agricultural systems (e.g. DFID 2004; references in Eyhorn 2007), and due to climate change that will on aggregate negatively affect agriculture and the suitability of land for farming in non-temperate climate zones (Hoogwijk et al. 2005; IPCC 2007, 2008).

Further issues of concern are a potential competition for the biomass itself between its use for energy generation and other uses, such as biomaterials or food (Gielen et al. 2001; Hoogwijk et al. 2003; Bringezu et al. 2007). This has repeatedly become manifest, e.g. by the rise of corn prices in Mexico due to increased demand from bio-ethanol factories in the US (NYT 2007). Important is also the criticism regarding life-cycle emissions and energy balance of liquid biofuels (Ulgiati 2001; Pimentel 2003; De Oliveira et al. 2005; Delucchi 2005, 2006; WWI 2006; Zah et al. 2007; Scharlemann and Laurence 2008). Similar to the competition for land, there is also a potential competition for water (Berndes 2002), which should be seen in the context of increasing water scarcity and global cereal trade (UNEP 2002; Yang et al. 2003; IPCC 2008). A recent and encompassing review of existing studies on bioenergy potential, land and water availability, economic constraints and other criteria is given in Lysen and van Egmond (2008).[2]

[1]Bioenergy: energy from biofuels; Biofuel: fuel produced directly or indirectly from biomass; Biomass: material of biological origin excluding material embedded in geological formations and transformed to fossil, such as: fuelwood, charcoal, agricultural wastes and by-products, energy crops, livestock manure, biogas, biohydrogen, bioalcohol, microbial biomass, and others. Bioenergy includes all wood energy and all agro-energy resources (FAO 2004).

[2]For completeness, I mention that Lysen and van Egmond (2008) and also other works, e.g. Rajagopal and Zilberman (2007), particularly point out the research gaps regarding economic aspects of bioenergy scenarios, such as costs of biomass supply and market interactions between biomass for food and energy.

Here, I address an additional challenge, which relates to biomass for energy use being an agricultural or forestry product. A natural matter of concern is the sustainability of this production, in particular in the context of the ongoing discussion of the adverse environmental effects of conventional agriculture (see Section 2). In the following, I relate the potentially huge production of biomass or demand for agricultural waste for energy to the problems of current agricultural production systems and to alternative agricultural production practises. I formulate the following hypothesis: the provision of sustainably grown agricultural products faces a strong trade-off with the provision of bioenergy, if both are to contribute significantly on a global scale.[3] The reason is the potential incompatibility of burning significant amounts of biomass for bioenergy production with alternative more sustainable forms of agriculture that rely on biomass inputs instead of inorganic fertilisers for their nutrient balance (see Section 3). This additional challenge further emphasises the necessity to incorporate a truly encompassing sustainability assessment into the discussion of climate change mitigation options based on bioenergy (cf. e.g. Paine et al. 1996; Hoogwijk et al. 2003; IFPRI 2006).[4]

The criticism put forth addresses 'modern'[5] bioenergy as an option to meet a significant share of total global energy demand. I emphasise that, duly adapted to the local situation, there are many promising options for single bioenergy projects that foster local sustainable development and help reduce rural poverty (e.g. UNDP

[3]There is an ongoing debate on yields in sustainable agriculture. In contrast to common wisdom, many authors report that productivity is not necessarily lower in such systems and replacing a significant part of conventional agricultural production with more sustainable alternatives such as organic agriculture (OA) needs not compromise food security (e.g. Badgley et al. 2007). These results however depend, among other factors, on the intensity of conventional agriculture OA is compared to (Sanders 2007). Sanders (2007) reviews the literature for Europe and reports lower yields by 20 to 40% for OA on average. However, especially for the South, where conventional agriculture is often less intensive, comparison to these systems may be adequate (Parrott and Marsden 2002). For further reading see e.g. Drinkwater et al. (1998), FAO (2002a), Maeder et al. (2002), Parrot and Marsden (2002), Pretty et al. (2006), Halberg et al. (2006), Badgley et al. (2007), Eyhorn (2007), Sanders (2007).

[4]Interestingly, the sustainability of biomass production is hardly a topic in the recent review of Lysen and van Egmond (2008). Only effects on biodiversity and protected areas are a concern, pesticide and fertiliser use and effects on soil fertility are mentioned only cursory (e.g. on p 28 and 78). Soil degradation itself is repeatedly a topic, but only as a constraint to land availability and productivity of biomass production, and not as an effect of such with conventional agricultural practices. These concerns are not even mentioned among the list of points NOT covered in this report (p 67 ff).

[5]'Modern' biomass refers to efficient state-of-the art systems to burn biomass directly or to convert it into liquid fuels or into gas used in adequate motors or stoves. 'Traditional' biomass is mainly used with very low efficiency for cooking in many developing countries. Examples for 'traditional' biomass are fuel wood, charcoal and dung cake. Currently, 'traditional' biomass accounts for roughly 10% of global primary energy supply. Only a fraction of 'traditional' biomass is renewable as it is usually not produced in a sustainable way (Goldemberg and Coelho 2004). 'Modern' biomass, other renewables (e.g solar) or fossil fuel is expected to replace the 'traditional' biomass currently used.

2000; Kartha and Leach 2001).[6] The problem addressed here only arises if the scale of total bioenergy production reaches certain high levels.

2 Conventional agriculture and sustainability in bioenergy production

Expansion of agricultural land is one of the most significant human alterations of the global environment and conventional agricultural production has often adverse effects on ecosystems. Key criteria to assess the environmental sustainability of agricultural systems are the performance regarding soil quality (organic matter content, water retention capacity, compactification), erosion, salinisation, water use (overuse of water bodies, water quality), biodiversity, nitrate leaching, pesticide and herbicide load. Measured against these criteria, many problems regarding long-term sustainability of conventional agriculture arise (Matson et al. 1997). The Global Environment Outlook 2 (UNEP 2000), for example, identifies the increasing nitrogen loading (whereof 60% are due to inorganic fertilisers used in conventional agriculture) as one of the major global environmental challenges. While acknowledging its immense successes regarding crop yields and food security (Evenson and Gollin 2003) and that it relieved poverty for hundreds of million of people between 1965 and 1990 (IFAD 2001), the green revolution (based on monocropping with high yield species, irrigation (where available) and increased use of inorganic fertilisers, herbicides and pesticides) also had many adverse affects regarding the criteria mentioned above. After forty years, this heritage has left a negative legacy in many countries (Matson et al. 1997; DFID 2004; references in Eyhorn 2007).

It is thus unclear whether this high intensity agriculture can be sustained. A further large increase in these production techniques due to the increase in biomass demand for bioenergy would exacerbate this problem. A gross mid-range estimate of the land area dedicated for bioenergy production may be around 500 Mha by 2050–2100 (e.g. Berndes et al. 2003; Azar 2004). This accounts for a third of the area currently used for agriculture (1530 Mha in the year 2000, FAO 2006). Other than land competition, this potential difficulty for environmental sustainability of large-scale[7] bioenergy production has not yet entered the broader discussion, although it is sometimes acknowledged (e.g. Giampietro and Ulgiati 1997; Krotscheck et al. 2000; UNDP 2000; Hoogwijk et al. 2005; Fritsche et al. 2006; Lewandowski and Faaij

[6]Small-scale on-site bioenergy systems bear considerable potential to increase livelihoods and to work towards poverty reduction especially in rural areas in the South, e.g. by replacing fuel wood with biogas. On-farm biogas production from organic material by capturing methane from anaerobic fermentation of dung and manure is an example (Bhat et al. 2001). Such projects are also realised under the Clean Development Mechanism, e.g. the biogas projects on household level Begapalli and Biogas Nepal Activity I and II or industrial projects based on swine manure (UNFCCC 2008). The raw material thus becomes a valuable resource and is no waste any longer and the fermented material can be applied as a high quality fertiliser. As with many innovative practises, though, the socioeconomic perspective is central and due account has to be paid to firmly anchor such new on-farm energy use practises in the community—otherwise efficient implementation is at risk. Bhat et al. (2001), for example, describe some accompanying measures that were crucial for the success of biogas plant dissemination in southern Karnataka, India.

[7]In this text, 'large-scale' always refers to the total amount of bioenergy and not to the size of single projects or installations.

2006; Rejinders 2006; WWI 2006; EEA 2006, 2007; Zah et al. 2007; Rajagopal and Zilberman 2007).[8]

Besides such more general approaches, there are many studies that address the environmental performance according to different criteria in specific settings and for specific bioenergy crops (e.g. Paine et al. 1996; Dworak et al. 2007; EEA 2007, many publications in the journal "Biomass & Bioenergy"). As in food crop production, large-scale monoculture high-input production of high-yield energy crops with annual harvest is likely to be particularly unsustainable, while certain types of forest use, perennial grasses or crops on marginal and degraded land (e.g. Jatropha) seem to be particularly promising (e.g. Francis et al. 2005; Jorgensen et al. 2005; EEA 2007). Similar conclusions are drawn in Zah et al. (2007), presenting a detailed overview on total ecological effects of various types of liquid biofuels and biogas. They find adverse ecological impacts in the production stage to be most important. This ecological impact varies among different crops, and they thus conclude that any policy supporting bioenergy should account for such encompassing environmental impact assessment. The best ecological performance is found for biomass waste, grass and wood.

There is also much research on yields of different energy crops and on how they can best be grown (e.g. several publications in the journal "Biomass & Bioenergy"). A research project specifically dedicated to the production of bioenergy in organic farming systems started in Danmark in 2006 (DARCOF 2007). Judging from the planned research, it tries to clarify several essential issues regarding the potential of bioenergy in OA, in particular as an option to reduce fossil fuel use on organic farms,

[8]Hoogwijk et al. (2005) mention that disregarding soil organic content reduction due to intensive farming practices may bias productivity estimates in their models. Fritsche et al. (2006) present a collection of sustainability criteria for bioenergy, based on an encompassing review of existing work. The recent World Bank study by Rajagopal and Zilberman (2007) explicitly criticises the widespread neglect of broader environmental concerns regarding bioenergy that not only account for greenhouse gases. EEA (2006, 2007) in detail assess the environmentally compatible bioenergy potential in Europe. They conclude that by 2030 a share of about 15% of the primary energy requirements of the EU-25 could be supplied by environmentally compatible bioenergy, but this result depends on some strong assumptions. First, the considerable amount of land under "environmentally-oriented" farming (labelled "organic" and "high nature value" farming) is modelled by lower yields only and the general assumption that this land would assure a certain level of environmental quality. The crucial aspect of organic matter nutrient balance in sustainable agriculture (cf. Section 3) seems to be addressed very cursory only, i.e. for gaseous bioenergy, where the slurry is recycled to the land, and via assumptions on a somewhat reduced availability of straw for burning from these lands. For forestry, organic matter nutrient balance is a topic as roots and foliage are left on site. For bioenergy from waste, however, it is assumed that there is no other use for this waste, thus conflicting with the necessity to use biomass waste in organic farming (cf. Section 3). Taking this into account, the bioenergy potential, which at least somewhat accounts for organic matter nutrient balance, amounts to about 5 to 6% of total primary energy use by 2030 only, instead of 15%. Furthermore, the model does account for competition for land between bioenergy and food on the export market only. On the other hand, the 15% of the study is a conservative estimate, as the land potentially available is estimated via reduction of food production due to increased global liberalisation of agricultural markets. Thus, different to the other studies on global land availability cited above, the amount of potentially suitable but currently not used land is not assessed. In addition, it is assumed that the European food self-sufficiency level does not change. This means, however, that on a global level the reduction in food export has to be produced somewhere else. In this model, the problem of land availability is thus shifted to other regions. A further assumption is that no reduction in currently extensively used land and protected forests takes place. This assures the corresponding environmental benefits.

but it does not address the potential problems of bioenergy as a significant share of world primary energy supply discussed here (cf. also Jorgensen et al. 2005).

Largely, potential problems of conventional agricultural practices for bioenergy production are acknowledged only in parts. In particular, systemic aspects of the compatibility of bioenergy production with more sustainable agricultural production practices on large scales are hardly addressed. In addition, in the studies which do address these aspects (e.g. Fritsche et al. 2006, EEA 2006, 2007; Zah et al. 2007; Rajagopal and Zilberman 2007) the pivotal role biomass plays as a fertiliser in more sustainable agricultural production systems is largely neglected (cf. endnote 8). I focus on this aspect in the following section.

3 Sustainable agriculture, closed cycle resource use and bioenergy

To avoid the problems of conventional agriculture, biomass for energy use needs to be produced sustainably. There exists a wide range of approaches to "sustainable agriculture" that outperform conventional agriculture on certain key aspects (see e.g. Eyhorn et al. 2003; Pretty et al. 2006), such as "integrated pest management" ("IPM", lowering pesticide use), or "no tillage" cultivation (improving soil structure and conservation). Most widely developed and implemented are the principles of organic agriculture and forestry management (OA). In the following, I focus on OA, because only this addresses all problems of conventional agriculture and provides a comprehensive system of interlinked and concerted measures for more sustainable agriculture.[9] It would, for example, account for almost all environmental concerns listed in the encompassing review of Fritsche et al. (2006).[10] Furthermore, it is based on well-established rules and institutionalisation, can rely on clearly defined certification and accreditation procedures and its share in agricultural production grows continuously (Eyhorn et al. 2003; IFOAM 2006b; Willer et al. 2008).

Organic agriculture focuses on nutrient cycles, soil protection, crop diversity and bio-control of pests and weeds (FAO 2002a; Eyhorn et al. 2003; IFOAM 2006b). These issues are closely interlinked, but for the argument made here, the first point is most important. Most plants can only take carbon and oxygen from the atmosphere (by photosynthesis from CO_2 resp. by plant respiration of O_2), only some species can take nitrogen from the atmosphere as well (e.g. Legumes by symbiosis with microbes). Most nitrogen and all the other nutrients are supplied via the soil. Thus either the stock of nutrients in the soil is run down, which is clearly an unsustainable solution, or it is replaced either by organic material or inorganic fertilisers.

Limits for sustainability on farm level are set by a closed nitrogen cycle on the level of the complex chemical compounds contained in organic material rather than

[9]Besides bio-dynamic agriculture, which is based on anthroposophic principles and includes a strong spiritual dimension. I will not address this approach.

[10]The performance of OA regarding GHG emissions reductions in comparison to conventional agriculture is subject to ongoing research. Reduced GHG emissions could occur due to increased soil organic matter contents, reduced energy consumption for fertiliser and pesticide production and use, and due to specific aspects of the farming system itself, such as a higher share in permanent grassland and tree cover (e.g. Kotschi and Müller-Sämann 2004; AgroEco 2006; IFOAM 2006a, 2007; Niggli et al. 2008).

by a closed carbon cycle on the level of chemical elements, as for bioenergy (Tilman 1997). Fertilising with organic matter has advantageous effects on soil structure and organic matter content, water retention capacity, biological activity, biodiversity and leads to soils that are less vulnerable to erosion (FAO 2002a). These effects cannot be attained by inorganic fertilisers focusing on nutrient input on the much lower complexity level of chemical elements. Therefore, OA depends on organic matter for fertilising and inorganic fertilisers cannot be used.

In OA, nutrient cycles are thus closed with the help of composting, mulching, green manuring, crop rotation, etc., thus replacing nutrients exported from the farm in the sold produce (food, cotton, etc. - or biomass for energy use). In such a farming system, as much biomass as possible should be reused on the farm, as availability of enough biomass is decisive and in fact often a problem for the organic farm. This is clearly accentuated the more biomass is exported from the farm (Eyhorn et al. 2003). Food export from the farm is only a part of the total biomass grown, whereas for bioenergy, it can approach close to 100% (e.g. if all crop-residues are combusted).[11] It thus seems to be impossible to burn biomass to a significant extent in the context of an organic farming system and the production of energy crops in organic farming systems faces fundamental incompatibilities. Or, phrased differently, large scale bioenergy production seems to be an option only in conventional agricultural systems and the possibility of large scale sustainable production of biomass for energy use is questionable.

One option to reconcile sustainable agriculture and bioenergy production may be certain crops such as Jatropha (Francis et al. 2005) or switchgrass on degraded, marginal and wastelands or in hedges between other crops. The potential share of such crops in total primary energy supply may be low, however (cf. also Hoogwijk et al. 2003, 2005). Jorgensen et al. (2005), for example, find in a study on Denmark that with such systems, only part of the on-farm energy use may be replaced.[12]

Another option would be to refrain from the standards of OA and to establish less comprehensive sustainable agricultural practices such as IPM. This is likely to be more compatible with bioenergy production. On the other hand, it would

[11]It has to be noted that not all agricultural residues are similarly ideal as a single base for organic fertilisers e.g. produced by composting. The raw materials for a good compost should be balanced between material with a high carbon/nitrogen ratio, with a low carbon/nitrogen ratio, and bulky material with rich structure (Eyhorn et al. 2003). Rice husk and sugar cane bagasse with their particularly low nitrogen content, for example, can only provide a fraction of the material for balanced composting. Thus, rice husk and bagasse based bioenergy projects—or projects based on any residue abundant in a region and not appropriate as a single basis for good compost or mulching—may be less problematic than projects based on other residues. Nevertheless, they can be used to produce compost or as a source for biomass in general and an organic strategy may well depend on their availability in case alternatives do not abound, given the general tendency of scarcity of biomass on organic farms.

Ash recycling does not solve the problem either, as ash is a mineral fertiliser containing mainly kalium, calcium and trace elements. It has to be supplemented with other fertilisers to deliver organic matter, phosphorous and nitrogen (Eyhorn et al. 2003). For further potential problems of wood ash application such as adverse effects on denitrification, see e.g. Odlare and Pell (2008).

[12]This paper addresses the problem of nutrient loss due to bioenergy and identifies certain cultures that are compatible with organic farming practices. A first estimate of the potential in Denmark suggests that 30–60% of the energy requirements of organic farms themselves could be covered by such practices. Thus, bioenergy in such a context may contribute significantly to on-farm energy use but would not be able to provide significant shares of total energy use beyond the farm.

only address a part of the problems identified for conventional agriculture (IPM, for example, allows inorganic fertiliser input). However, detailed assessment of this trade-off would be necessary.

Duly managed forestry systems, where nutrient loss can be kept on a low level by on-site foliage, for example, could also be options for sustainably grown biomass for energy use (EEA 2006 and references therein). How sustainable these practises are in the long-run, however, needs further investigation. Paradigms of sustainable forestry and development of adequate sustainability indicators are still subject to discussions, especially in the light of its increasingly important role in the bioenergy context (e.g. Smith 1995; Kimmins 1997; Moffat 2003). In addition, the potential for biomass from forestry accounts for a fraction of total bioenergy supply in most models only.[13]

Besides growing biomass for energy use, there is the option to use waste biomass for energy production. Using biomass waste for energy production eliminates the negative side effects of open biomass waste burning or deposition (methane, odour, smog and dust emissions) and generates useful heat and power as well. Examples are organic household waste and waste from rice (rice husk), sugar (bagasse) or palm oil (fruit shells) production. A large number of such projects are realised under the Clean Development Mechanism (CDM), for example, and detailed information is available from the Project Development Documents (PDD) (UNFCCC 2008). In spite of the positive aspects of using these resources for energy production, the question arises, whether increased use of biomass waste for energy production may hinder the development and spread of sustainable agricultural practices that rely on the (regional) presence of large enough quantities of biomass for their nutrient balance.

The PDDs of the CDM provide some evidence for such barriers. Bioenergy projects may constrain fuel supply for local industries such as brick makers.[14] There is also ample evidence that such bioenergy projects lead to (regional) increases in biomass prices.[15] Such projects resulting in increased demand for biomass thus also affect agricultural practises, such as organic farming, relying on composted crop residues, etc. as fertiliser. The potential for such a dynamic is also acknowledged for bioenergy plants in Europe (EEA 2007).

In case of increased organic agricultural production, e.g. due to sustainable development policies to reduce the negative impact of conventional agriculture[16], competition for biomass between bioenergy and organic farming systems could thus emerge. This could also happen on a regional level, in case establishment of

[13] Some examples: about a fifth in EEA (2006); at most a third in Hoogwijk et al. (2003), for the most extreme scenarios, and considerably less for others; 40% in Parikka (2004); less than 10% in the studies reviewed in Berndes et al. (2003), except for three studies based on much higher extraction rates from forests. Such intensive harvesting may be unsustainable, though (Smith 1995).

[14] An example is the CDM project with reference Nr. 0476 (UNFCCC 2008), where such a switch is mentioned, but it is not assessed whether the brick kilns switch to other fuels, and if so, of which type (more/less efficient and polluting), or whether they stop production.

[15] Many CDM biomass projects provide this evidence, as can be seen from their PDDs; see e.g. projects Nr. 926, 936, 950, 1026 for an arbitrary choice of examples (UNFCCC 2008).

[16] See e.g. Rundgren (2008) for some detailed country case studies or FAO (2003) referring to India, which in its 9th and 10th Five Year Plans substantially promotes organic agriculture on a national level.

bioenergy plants threatens organic farming initiatives in the same region due to their biomass needs.

4 Conclusions

Bioenergy is seen as a promising option to reduce GHG emissions. Correspondingly, policy and state assistance is steadily increasing, bioenergy use is extending and technologies are developing fast. However, the long-term impacts of bioenergy providing a significant share of world energy demand need to be analysed in more depth. Sustainable policies must also include aspects other than avoided greenhouse gas emissions. Besides the reservations tied to food price and land rent increases due to the land competition between food and bioenergy crops, there are reservations regarding the increasing water scarcity and, especially, regarding the way bioenergy is grown on the fields.

First, large-scale agricultural biomass production for energy use may be essentially impossible if it should be done in a truly sustainable way (e.g. according to the principles of organic agriculture), based on closed nutrient cycles, where the biomass that is not exported from the farm in form of the final produce, is reused on the farm as fertiliser (via composting, mulching, etc.).

Second, biomass for energy use from some forestry practises or from some crops on marginal land are likely to be a sustainable alternative, but may not have the potential to supply large enough amounts to supply significant shares of global primary energy use. More research on this is needed.

Third, bioenergy from agricultural waste may also be more sustainable, in particular in a context of conventional farming systems. But it is not clear how much of such residuals would actually be available for energy production in a region of largely organic farming practises, due to their dependence on a sufficient supply of biomass for their functioning. Biomass is usually not abundant on organic farms.

It is thus unclear if the amount of biomass needed to supply a significant share of global energy use can be produced in a truly sustainable manner. Conventional agriculture may be the only way to produce such biomass quantities. The bioenergy option may lead to a lock-in situation, making sustainable agriculture impossible. The potential trade-off between policies to foster bioenergy for "sustainable" world energy and policies to increase sustainable agriculture must therefore be kept in mind.

Acknowledgements Many thanks to Simon Mason, Reinhard Madlener, Daniel Johansson and, in particular, Cecile van Hezik for their thoughtful comments and to Frank Eyhorn who first pointed out the potential problem of OA and bioenergy to me. I also thank Thomas Sterner and the Environmental Economics Unit at the Göteborg University for their hospitality. Financial support from the Swiss National Science Foundation is gratefully acknowledged. The usual disclaimer applies.

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